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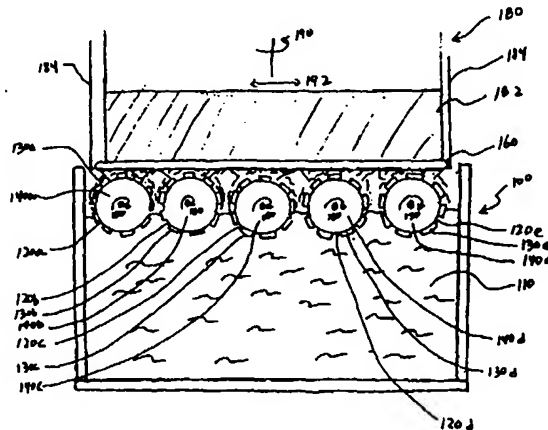
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- (71) Applicant: NUTOOL, INC. [US/US]; 1645 McCandless Drive, Milpitas, CA 95035 (US).
- (72) Inventors: UZOH, Cyprian, E.; 1645 McCandless Drive, Milpitas, CA 95035 (US). TALIEH, Homayoun; 2211 Bentley Ridge Drive, San Jose, CA 95138 (US). BASOL, Bulent; 3001 Maple Avenue, Manhattan Beach, CA 90266 (US). YOUNG, Douglas, W.; 147 North Murphy Avenue, Sunnyvale, CA 94086 (US).
- (74) Agents: JAKOPIN, David, A. et al.; Pillsbury Madison & Sutro LLP, 1100 New York Avenue, N.W., Washington, DC 20005 (US).
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(54) Title: SEMICONDUCTOR WORKPIECE PROXIMITY PLATING METHODS AND APPARATUS



(57) Abstract: The present invention relates to methods and apparatus for plating a conductive material on a semiconductor substrate by rotating pad or blade type objects in close proximity to the substrate, thereby eliminating/reducing dishing and voids. This is achieved by providing pad or blade type objects mounted on cylindrical anodes or rollers and applying the conductive material to the substrate using the electrolyte solution disposed on or through the pads, or on the blades. In one embodiment of the invention, the pad or blade type objects are mounted on the cylindrical anodes and rotated about a first axis while the workpiece may be stationary or rotate about a second axis, and metal from the electrolyte solution is deposited on the workpiece when a potential difference is applied between the workpiece and the anode. In another embodiment of the present invention, the plating apparatus includes an anode plate spaced apart from the cathode workpiece. Upon application of power to the anode plate and the cathode workpiece, the electrolyte solution disposed in the plating apparatus is used to deposit the conductive material on the workpiece surface using cylindrical rollers having the pad or blade type objects.

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SEMICONDUCTOR WORKPIECE PROXIMITY PLATING METHODS AND APPARATUS

Field of the Invention

5 The present invention relates to methods and apparatus for plating a conductive material on a semiconductor substrate. More particularly, the invention is directed to "proximity plating" methods and apparatus for plating the conductive material on the semiconductor substrate. The substrate is plated with the conductive material as the pad and/or blade type objects are rotated in close proximity to the substrate.

10 Background of the Invention

 A conventional process step in the manufacturing of integrated circuits and devices involves plating a conductive layer on a semiconductor substrate. Plating the substrate with the conductive material over a seed layer has important and broad application in the semiconductor industry. Traditionally, aluminum and other metals are deposited as one of many conductive layers that make
15 up a semiconductor chip. However, in recent times, there is great interest in copper deposition for interconnects on semiconductor chips, because, compared to aluminum, copper reduces electrical resistance and allows semiconductor chips to run faster with less heat generation, resulting in a significant gain in chip capacity and efficiency.

 Typically, the semiconductor substrate has been previously etched and contains many holes
20 and/or trenches on its surface. One goal of plating is to uniformly fill the holes and trenches with the conductive material.

 However, as known in the art, conventional plating methods result in "dishing" or non-planar deposition during the plating process. In Fig. 1A, a barrier layer 4 and a seed layer 6 is disposed upon a substrate 2, where a section of the substrate 2 includes a trench 12. After forming the barrier layer 4
25 and the seed layer 6, a conductive layer 8 is plated on top of the seed layer 6. Because the trench 12 may be relatively large, a recess 10 is formed thereon and dishing results.

 For small features with sub-micron size dimensions, existence of voids in the deposited conductive layer is a common problem. In Fig. 1B, such a void 14 is formed near the bottom of a narrow hole 16. It is well known that the existence of such voids in the deposited conductive layer
30 results in defective devices with poor performance. Accordingly, this invention provides a more accurate, fast, cost effective, and reliable manner of applying the conductive material to the semiconductor substrate.

Summary of the Invention

 It is an object of the invention to provide methods and apparatus that deposit a conductive

material on a substrate with the pad or blade type objects rotating in a circular manner.

It is another object of the invention to provide methods and apparatus that deposit a conductive material on a substrate while eliminating/reducing dishing and voids.

It is yet another object of the invention to provide methods and apparatus that deposit a
5 conductive material on a substrate using novel pad-anode or blade-anode assemblies.

These and other objects of the present invention are obtained by providing methods and apparatus for depositing a conductive material from an electrolyte solution to the substrate. This is achieved by providing pad or blade type objects mounted on cylindrical anodes or rollers and applying the conductive material to the substrate using the electrolyte solution disposed on or through the
10 pads or on the blades.

An apparatus that performs such plating includes anodes and a cathode workpiece that are in close proximity of each other. The pad or blade type objects mounted on the cylindrical anodes or rollers rotate about a first axis and the workpiece may be stationary or rotate about a second axis, and metal from the electrolyte solution is deposited on the workpiece when a potential difference is
15 applied between the workpiece and the anode.

Alternatively, the plating apparatus may include an anode plate spaced apart from the cathode workpiece. Upon application of power to the anode plate and the cathode workpiece, the electrolyte solution disposed in the plating apparatus is used to deposit the conductive material on the workpiece surface using cylindrical rollers having the pad or blade type objects.

Further, in another embodiment, the plating apparatus may include an anode plate spaced apart from cylindrical cathodes having conductive pads or blades. Upon application of power to the anode plate and the cathodes and upon rotating the cathodes in a circular direction, the conductive pads or blades make electric contact to the workpiece surface rendering it cathodic with respect to the anode plate, and metal from an electrolyte solution is deposited on the same surface.

25 Brief Description of the Drawings

These and other objects and advantages of the present invention will become apparent and more readily appreciated from the following detailed description of the presently preferred exemplary embodiments of the invention taken in conjunction with the accompanying drawings, of which:

Fig. 1A illustrates a cross sectional view of a conductive layer disposed on a substrate with
30 "dishing" characteristics;

Fig. 1B illustrates a cross sectional view of a substrate having a hole containing a void therein;

Fig. 2 illustrates a cross sectional view of a substrate having a conductive layer where dishing is eliminated/reduced;

Fig. 3 illustrates a cross sectional view of a "proximity plating" apparatus in accordance with

the first preferred embodiment of the invention;

Figs. 4A - 4B illustrate perspective views of pad-anode assemblies in accordance with the preferred embodiment of the invention;

5 Figs. 5-6 illustrate cross sectional views of embodiments using anode rods in accordance with the preferred embodiment of the invention;

Fig. 7 illustrates a cross sectional view of a "proximity plating" apparatus in accordance with the second preferred embodiment of the invention; and

Fig. 8 illustrates a cross sectional view of a "proximity plating" apparatus in accordance with the third preferred embodiment of the invention.

10 Detailed Description of the Preferred Embodiments

The preferred embodiments of the present invention will now be described with reference to Figs. 2- 8. The inventors of the present invention herein disclose methods and apparatus for "proximity plating" a conductive material on a semiconductor substrate. The present invention contemplates different embodiments to be used to plate/deposit a conductive material onto the
15 substrate and into the contacts, vias, holes, trenches, and the like. While the present invention can be used with any conductive material, it is especially suited for use with copper as the conductor and for use in the fabrication of VLSI and ULSI integrated circuits having submicron size features. Furthermore, semiconductor workpieces such as a wafer, a flat panel, magnetic film head, or the like may be used in accordance with the present invention.

20 An example of a proximity plating method and apparatus is disclosed in a co-pending U.S. Application Serial No. 09/285,621, entitled "Method and Apparatus For Plating and Polishing a Semiconductor Substrate", commonly owned by the assignee of the present invention, the contents of which are expressly incorporated herein by reference. The present invention discloses alternative embodiments.

25 One object of the invention is to eliminate dishing. Fig. 2 illustrates a cross sectional view of a substrate where dishing is eliminated/reduced as the conductive layer 8 is deposited onto the substrate 2. A relatively uniform flat conductive layer 8 can be obtained by plating the conductive material at a high mass transfer rate, as described in more detail in the present invention. Another object of the present invention is to eliminate voids in the plated material. Eliminating/reducing
30 dishing and eliminating voids are highly desirable in order to manufacture a high quality integrated circuit/device.

Fig. 3 illustrates a cross sectional view of a "proximity plating" apparatus in accordance with the first preferred embodiment of the present invention. Fig. 3 illustrates a nonconductive chamber 100 having an electrolyte solution 110 disposed therein. The chamber 100 includes anode assemblies

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120a, 120b, etc., having multiple strips of pads 130a, 130b, etc., mounted, or machined onto the cylindrical anodes 140a, 140b, etc. The cylindrical anodes 140a, 140b, etc., may be hollow cylinders formed from conductors such as carbon and titanium having a diameter between 10 to 30 mm.

As shown, the cylindrical anodes 140a, 140b, etc., are in partial contact with the electrolyte solution 110. In other words, the top level of the electrolyte solution 110 is below the surface of a workpiece 160 (i.e., the top level of the electrolyte solution 110 does not make direct contact with the workpiece surface when the cylindrical anodes 140a, 140b, etc., are stationary). Alternatively, the electrolyte solution 110 may be making contact with the workpiece 160 surface.

During operation, a voltage is applied between the cylindrical anodes 140a, 140b, etc., and a cathode workpiece 160. Electrical contact to the cathode workpiece 160 is made via cathode contacts 184. When the anodes 140a, 140b, etc., and the pad strips (or pads) 130a, 130b, etc., are rotating about axis 150 in either a clockwise or counterclockwise direction, and are spaced apart from the cathode workpiece 160 (the pad strips 130a, 130b, etc. do not make direct contact with the workpiece 160, or alternatively, make only slight contact), the workpiece 160 is plated using the electrolyte solution 110.

The anodes 140a, 140b, etc. and the pad strips 130a, 130b, etc. should preferably rotate at a rate such that the electrolyte solution 110 is continuously "picked" by the anodes 140a, 140b, etc., and applied/splashed onto the workpiece 160. They may all rotate in the same clockwise or counterclockwise direction or alternatively, some may rotate in one direction (i.e., clockwise) while others may rotate in the opposite direction (i.e., counterclockwise). Further, during operation, one, two, three,..., or all anodes 140a, 140b, etc., may be activated concurrently and voltages may be applied to all or only a selected number of them. Anode current densities for different anodes 140a, 140b, etc., may vary, and this can be used to control the uniformity of the deposited material across the workpiece 160. In addition, the length of the anodes 140a, 140b, etc., may all be the same or they may be different.

When the gaps between the pads 130a, 130b, etc., and the workpiece 160 are about 0-5 mm and contains a meniscus of electrolyte solution 110, a very high mass transport results, thereby depositing high quality metal films onto the workpiece 160. Moreover, when electric power is applied to the cylindrical anodes 140a, 140b, etc., and the cathode workpiece 160, a closed electrical circuit is formed through the anode assemblies 120a, 120b, etc., the applied/splashed electrolyte solution 110 in the gaps, and the workpiece 160. This is described in more detail below. Moreover, depending on the type, shape, and structure of the pads 130a, 130b, etc., the gaps may be greater than 5 mm.

The workpiece head assembly 180 may include a nonconductive, preferably circular chuck 182 with a cavity that is preferably a few millimeters deep at its center and which cavity may contain a resting pad (not shown). The workpiece 160 is loaded into the cavity, backside first, against the resting pad using a conventional type of transport or vacuum mechanism to ensure that the workpiece 160 is stationary with respect to the workpiece head assembly 180 while in use. A nonconductive retaining ring (not shown) such as an O-ring or other rubber type of seal at the periphery of the workpiece head assembly 180 and the cathode contacts 184 each push against the edge of the workpiece 160 and hold it in place. The entire back side of the workpiece 160 which pushes against the chuck 182 that is under the retaining ring is thus protected from any and all solutions, including electrolyte. Other conventional workpiece head assemblies can be used in accordance with the invention.

As shown, the workpiece head assembly 180 faces toward the anode assemblies 120a, 120b, etc. The head assembly 180 may be stationary or rotate around axis 190 using a conventional motorized spindle (not shown). The head assembly 180 may also be adapted to move up and down and/or side to side in the direction of arrow 192 so that the workpiece 160 may be plated more effectively.

Instead of using the cathode contacts 184 described above, the electric potential can be applied to the workpiece 160 using a ring conductor. Further, other methods of applying the electric potential to the workpiece may be used in accordance with the present invention. For example, a liquid conductor or an inflatable tube coated with a conductive material may be used in the present invention. An example of using the liquid conductor or the conductive tube to provide the necessary electric potential is disclosed in the co-pending U.S. Application Serial No. 09/283,024, entitled "Method And Apparatus For Forming an Electric Contact With a Semiconductor Substrate", commonly owned by the assignee of the present invention, the contents of which are expressly incorporated herein by reference. What is important to note from the previous examples is that any method for providing an electric potential between the anode or anodes and the cathode workpiece can be used in the present invention.

Fig. 4A illustrates a perspective view of a first pad-anode assembly in accordance with the present invention. An anode assembly 122 (120a, 120b, etc. in Fig. 3) includes a unique pad-anode arrangement for plating the workpiece 160. Multiple strips of pad 132 (130a, 130b, etc. in Fig. 3) are attached, glued, or machined onto a cylindrical anode 142 (140a, 140b, etc. in Fig. 3) such that the pads 132 protrude from the outer surface of the anode 142. In this arrangement, the pads 132 are formed on the anode 142 in a circular manner such that the pads 132 wrap around the anode 142. The cylindrical anode 142 is further connected to a shaft 192 for rotating about axis 150.

Fig. 4B illustrate a perspective view of a second pad-anode assembly in accordance with the preferred embodiment of the present invention. Again, the anode assembly 124 (120a, 120b, etc. in Fig. 3) includes a unique pad-anode arrangement for plating the workpiece 160. Similar to Fig. 4A, multiple strips of pad 134 (130a, 130b, etc. in Fig. 3) are attached, glued, or machined onto a cylindrical anode 144 (140a, 140b, etc. in Fig. 3) such that the pads 134 protrude from the outer surface of the anode 144. However, in this arrangement, the pads 134 are formed on the anode 144 in a manner such that the pads 134 run along the longitudinal side of the cylindrical anode 144 in a substantially straight manner. This is illustrated in Fig. 4B. The cylindrical anode 144 is further connected to a shaft 194 for rotating about axis 150.

It should be appreciated that many other designs of pad strips can also be used effectively in the present invention. What is important is that these strips cause rigorous stirring of the electrolyte at the workpiece surface. The pad strips described thus far in Figs. 3, 4A, and 4B are relatively wide (2 to 20 mm). In other embodiments, narrow strips (1 to 2 mm) that are shaped like blades can be used in the present invention. These blades are of a type similar to windshield wiper blades used in automobiles and are made preferably from polymeric materials that are compatible with the plating solution used in the invention. The pad strips may be made of a porous or non-porous polymeric material with or without abrasive particles contained therein. Both the pad strips and blades can be rigid or flexible. What is important is that the pad strips/blades material is stable and can be employed in conjunction with various plating solutions that can be used in this invention.

In another embodiment of the invention, the pad strips or blades 130a, 130b, etc., in Fig. 3 may be made of a conductive material. In this case, it should be assured that the pad strips or blades 130a, 130b, etc., do not touch the workpiece 160 surface during the plating operation, as described in more detail later herein.

Figs. 5-6 illustrate cross sectional views of embodiments using anode rods in accordance with the preferred embodiment of the invention. In these embodiments, rather than having one large cylindrical anode for each anode assembly as shown in Fig. 3, multiple anode rods are enclosed in cylindrical anode assemblies. For example, Fig. 5 illustrates an anode assembly 300 having multiple anode rods 310a, 310b, etc., extending from one end of the assembly 300 to the other end within the cylindrical space contained by the wall 300a. Preferably, the anode rods are between 1 mm to 3 mm in diameter. Although the anode rods 310a, 310b, etc., are schematically shown as not in contact with each other, the anode rods 310a, 310b, etc., may be in contact with each other in other embodiments. Furthermore, anode pellets of various shapes and sizes may be substituted for anode rods in the cylindrical cavity within the walls 300a or a combination of anode rods and pellets may be used.

The anode assemblies of Figs. 5 and 6 should preferably include pores/holes 300b, as shown

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herein. The plating solution can enter the cylindrical cavity through the pores/holes 300b, thereby forming an electrical and physical contact between the plating solution and the anode rods/pellets.

The anode assembly 300 also includes pads 320 (130a, 130b, etc. in Fig. 3) as described earlier. A shaft 330 extends through the center of the anode assembly 300 such that the anode assembly 300 may be rotated in a circular motion (either clockwise or counterclockwise). The material 340 surrounding the rods/pellets 310a, 310b, etc, and the shaft 330 is preferably made from an insulating polymeric material. The anode rods/pellets 310a, 310b, etc., are preferably made from the same material that is deposited on the workpiece. For example, for Cu deposition, rods/pellets 310a, 310b, etc., should be preferably made from Cu. The rods/pellets 310a, 310b, etc., may be replaced occasionally as they are in constant use.

Fig. 6 illustrates an anode assembly 350 similar to that of Fig. 5 except blades 360 are used instead of pads 320.

Fig. 7 illustrates a cross sectional view of another embodiment of the present invention where a separate anode plate is used instead of the cylindrical anodes. A chamber 400 includes one or more cylindrical rollers 410a, 410 b, etc., having pad type objects 420a, 420b, etc., attached/mounted thereon. The rollers 410a, 410b, etc., are preferably made from polymeric materials or metals such as Ti that are chemically and mechanically stable in an electrolyte solution 440. The pad type objects 420a, 420b, etc., are attached, mounted, etc. on the rollers 410a, 410b, etc., in a manner similar to that described with reference to Fig. 3.

The chamber 400 includes an anode plate 460 on the bottom of the chamber 400. Any known method for attaching the anode plate 460 to the bottom of the chamber 400 may be used. In the alternative, the anode plate 460 may be positioned at any other location in the chamber 400 so long as it makes physical contact with the electrolyte solution 440. The electrolyte solution 440 in the chamber 400 also makes contact with the pads 420a, 420b, etc. The electrolyte solution 440 can be originally fed into the chamber 400 via a reservoir (not shown) through an in-channel (not shown).

Upon application of power between the workpiece 160 via, for example, contacts 184 and the anode plate 460, and upon rotating one or more rollers 410a, 410b, etc. about axis 450 in either a clockwise or counterclockwise direction, the electrolyte solution 440 is continuously splashed/applied to the workpiece 160 via pads 420a, 420b, etc. Shafts 470a, 470b, etc., are used to rotate the rollers 410a, 410b, etc, respectively. Thus, metal is plated out of the electrolyte solution 440 onto the workpiece 160 surface. As disclosed earlier herein, rollers with blade type objects instead of pads can be used.

In another embodiment of the present invention, the pad/blade 420a, 420b, etc. material in Fig. 7 may be constructed/made from a highly conductive fabric or polymeric material such as

15. The apparatus according to claim 14, wherein the plurality of anode assemblies further includes a plurality of holes.

16. The apparatus according to claim 1, wherein the workpiece comprises one of a wafer, a flat panel, and a magnetic film head.

17. A method of depositing a conductive material on a surface of a workpiece, comprising the steps of:

applying a voltage between a plurality of anodes having pad or blade strips and the workpiece; rotating the plurality of anodes in a circular direction; and

continuously applying an electrolyte solution having the conductive material to the surface of the workpiece as the plurality of anodes are rotated in the circular direction.

18. The method according to claim 17, wherein the plurality of anodes comprise of cylindrical anodes.

19. The method according to claim 18, wherein the cylindrical anodes comprises hollow cylinders.

20. The method according to claim 19, wherein the cylindrical anodes comprise one of carbon and titanium.

21. The method according to claim 19, wherein the cylindrical anodes comprise diameters between 10 to 30 mm.

22. The method according to claim 17, wherein a first predetermined number of the plurality of anodes are rotated in a clockwise direction and a second predetermined number of the plurality of anodes are rotated in a counterclockwise direction.

23. The method according to claim 17, wherein the electrolyte solution is flowed through passageways and holes in the plurality of anodes to the surface of the workpiece.

24. The method according to claim 17, wherein the pad or blade strips are attached to outer surfaces of the plurality of anodes.

25. An apparatus for depositing a conductive material on a surface of a workpiece, comprising:
a workpiece head assembly adapted to support the workpiece; and

a chamber having:

a plurality of rollers, wherein each roller is adapted to rotate in a circular direction and includes one or more pad or blade strips attached to an outer surface of the roller;

an electrolyte solution including the conductive material, the electrolyte solution adapted to be applied to the surface of the workpiece upon rotating the plurality of rollers; and

an anode plate positioned in the chamber such that the electrolyte solution makes contact with the anode plate.

26. The apparatus according to claim 25, wherein the anode plate is positioned on a bottom wall of the chamber.

27. The apparatus according to claim 25, wherein the anode plate is positioned on a side wall of the chamber.

28. The apparatus according to claim 25, wherein the one or more pad or blade strips are wrapped around the outer surface of the roller.

29. The apparatus according to claim 25, wherein the one or more pad or blade strips are attached to the outer surface of the roller along a longitudinal side of the roller.

30. The apparatus according to claim 25, wherein the workpiece head assembly is further adapted to move up and down and side to side.

31. The apparatus according to claim 25, wherein the workpiece head assembly is further adapted to rotate in a clockwise or counterclockwise direction.

32. The apparatus according to claim 25, wherein the one or more pad strips include width that are 2 - 20 mm.

33. The apparatus according to claim 25, wherein the one or more blade strips include width that are 1 - 2 mm.

34. The apparatus according to claim 25, wherein the one or more pad strips comprise one of porous, non-porous, conductive, and non-conductive material.

35. The apparatus according to claim 25, wherein the one or more pad strips further include abrasive particles.

36. A method of depositing a conductive material on a surface of a workpiece, comprising the steps of:

applying a voltage between an anode plate and the workpiece;

rotating a plurality of rollers having pad or blade strips in a circular direction; and

continuously applying an electrolyte solution having the conductive material to the surface of the workpiece as the plurality of rollers are rotated in the circular direction.

37. The method according to claim 36, wherein the plurality of rollers comprise of cylindrical rollers.

38. The method according to claim 37, wherein the cylindrical rollers comprise hollow cylinders.

39. The method according to claim 38, wherein the cylindrical rollers comprise diameters between 10 to 30 mm.

40. The method according to claim 36, wherein a first predetermined number of the plurality of rollers are rotated in a clockwise direction and a second predetermined number of the plurality of

rollers are rotated in a counterclockwise direction.

41. The method according to claim 36, wherein the pad or blade strips are attached to outer surfaces of the plurality of rollers.

42. A method of depositing a conductive material on a surface of a workpiece, comprising the steps of:

applying a voltage between an anode plate and a plurality of rollers having conductive pads or blade strips, wherein the pads or blades strips make contact with the workpiece;

rotating a plurality of rollers having pad or blade strips in a circular direction; and

continuously applying an electrolyte solution having the conductive material to the surface of the workpiece as the plurality of rollers are rotated in the circular direction.

43. The method according to claim 42, wherein the plurality of rollers comprise of cylindrical rollers.

44. The method according to claim 42, wherein the cylindrical rollers comprise hollow cylinders.

45. The method according to claim 44, wherein the cylindrical rollers comprise diameters between 10 to 30 mm.

46. The method according to claim 42, wherein a first predetermined number of the plurality of rollers are rotated in a clockwise direction and a second predetermined number of the plurality of rollers are rotated in a counterclockwise direction.

47. The method according to claim 42, wherein the pad or blade strips are attached to outer surfaces of the plurality of rollers.

48. An apparatus for depositing a conductive material on a surface of a workpiece, comprising:

a workpiece head assembly adapted to support the workpiece; and

a chamber having:

a plurality of anode assemblies, wherein each anode assembly is adapted to rotate in a circular manner and includes an anode, one or more pad or blade strips attached to an outer surface of the anode, and means for introducing an electrolyte solution having the conductive material to the one or more pad or blade strips such that the conductive material is applied to the surface of the workpiece upon rotating the plurality of anode assemblies.

49. The apparatus according to claim 48, wherein the anode comprises of a cylindrical anode.

50. The apparatus according to claim 49, wherein the one or more pad or blade strips are wrapped around the outer surface of the cylindrical anode.

51. The apparatus according to claim 49, wherein the one or more pad or blade strips are attached to the outer surface of the anode along a longitudinal side of the cylindrical anode.

52. The apparatus according to claim 48, wherein the workpiece head assembly is further adapted to move up and down and side to side.

53. The apparatus according to claim 48, wherein the workpiece head assembly is further adapted to rotate in a clockwise or counterclockwise direction.

54. The apparatus according to claim 48, wherein the one or more pad strips include width that are 2 - 20 mm.

55. The apparatus according to claim 48, wherein the one or more blade strips include width that are 1 - 2 mm.

56. The apparatus according to claim 48, wherein the one or more pad strips comprise one of porous, non-porous, conductive and none-conductive material.

57. The apparatus according to claim 56, wherein the one or more pad strips further include abrasive particles.

58. The apparatus according to claim 48, wherein the means for introducing the electrolyte solution comprises passageways and holes in the plurality of anode assemblies.

59. The apparatus according to claim 48, wherein the workpiece comprises one of a wafer, a flat panel, and a magnetic film head.

60. The apparatus according to claim 48, wherein the electrolyte solution comprises an electroless deposition solution.

61. The apparatus according to claim 60, wherein the electroless deposition solution comprises one of Cu, Ni, Ni-P, and Co.

62. A method of etching a conductive material on a surface of a workpiece, comprising the steps of:

applying a zero voltage between one or more anodes having pad or blade strips and the workpiece;

rotating the one or more anodes in a circular direction; and

applying an etching solution to the surface of the workpiece as the one or more anodes are rotated in the circular direction.

63. A method of electroetching a conductive material on a surface of a workpiece, comprising the steps of:

applying a voltage between one or more anodes having pad or blade strips and the workpiece, wherein the voltage at the workpiece is more positive than the voltage at the one or more anodes;

rotating the one or more anodes in a circular direction; and

applying an etching solution to the surface of the workpiece as the one or more anodes are rotated in the circular direction.

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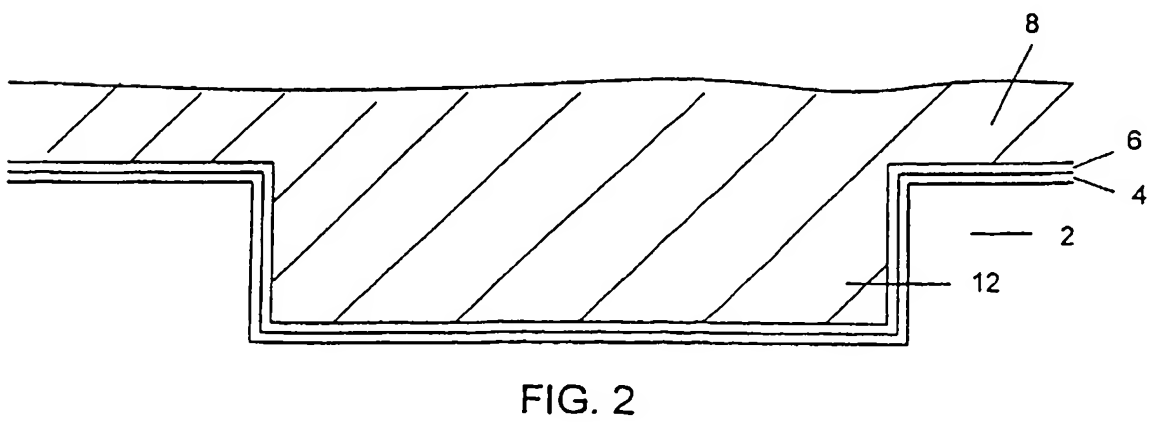
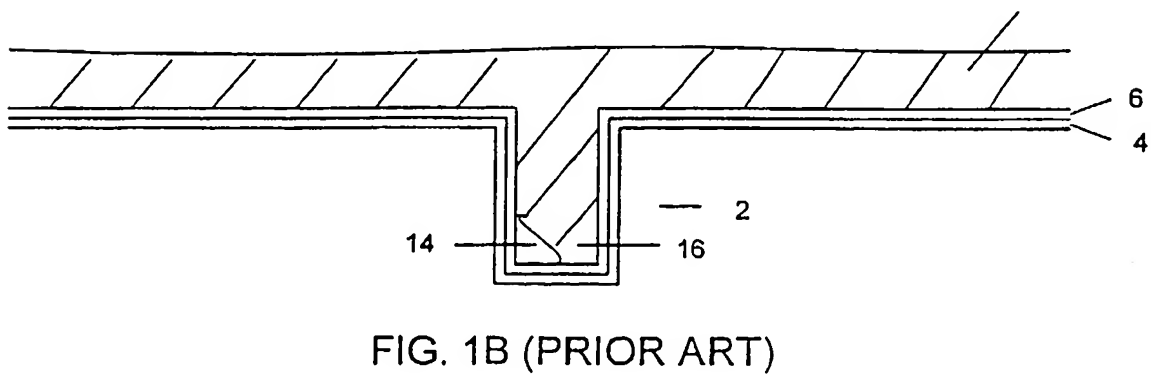
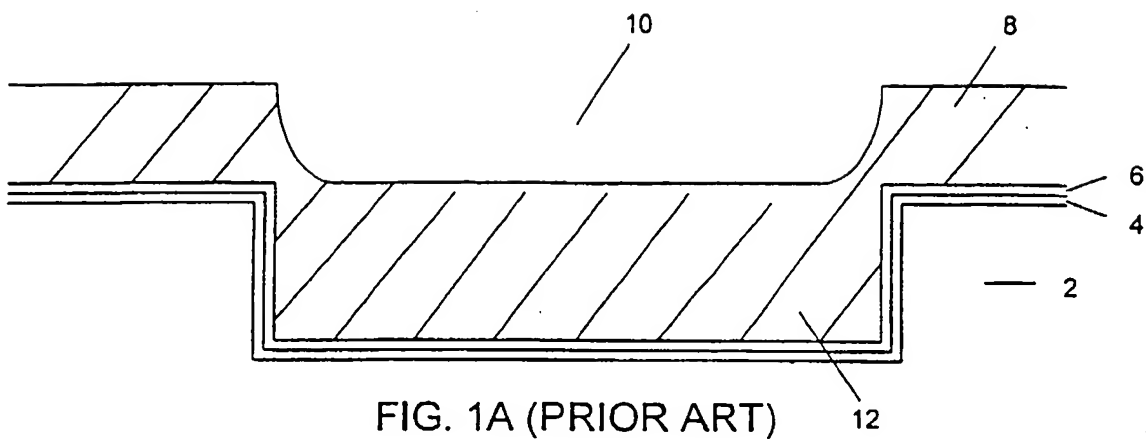
64. A method of electroetching a conductive material on a surface of a workpiece, comprising the steps of:

applying a voltage between an anode plate and workpiece, wherein the voltage at the workpiece is more positive than the voltage at the anode plate;

rotating one or more rollers having pad or blade strips in a circular direction; and

applying an etching solution to the surface of the workpiece as the one or more rollers are rotated in the circular direction.

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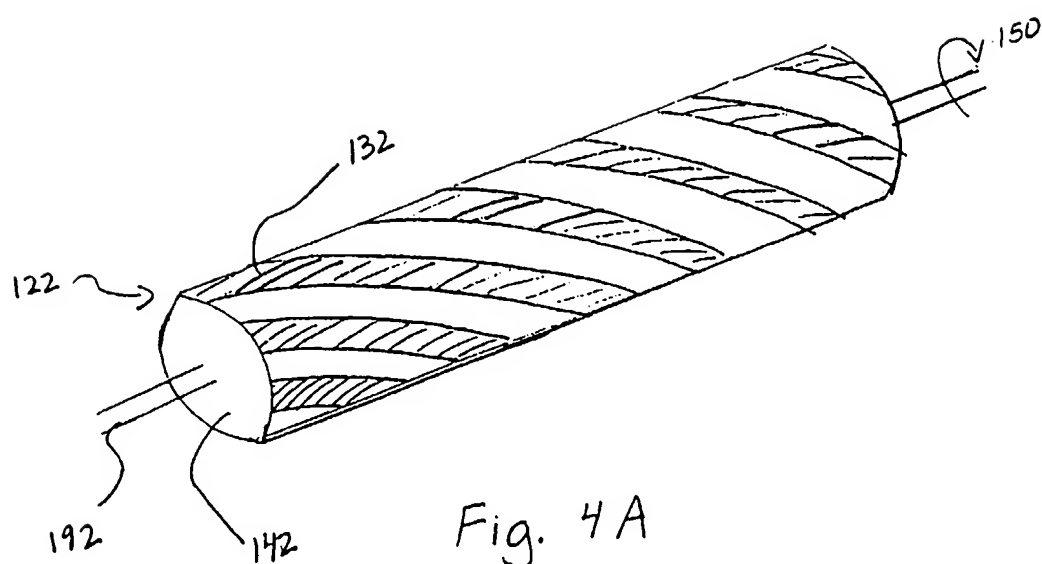


Fig. 4A

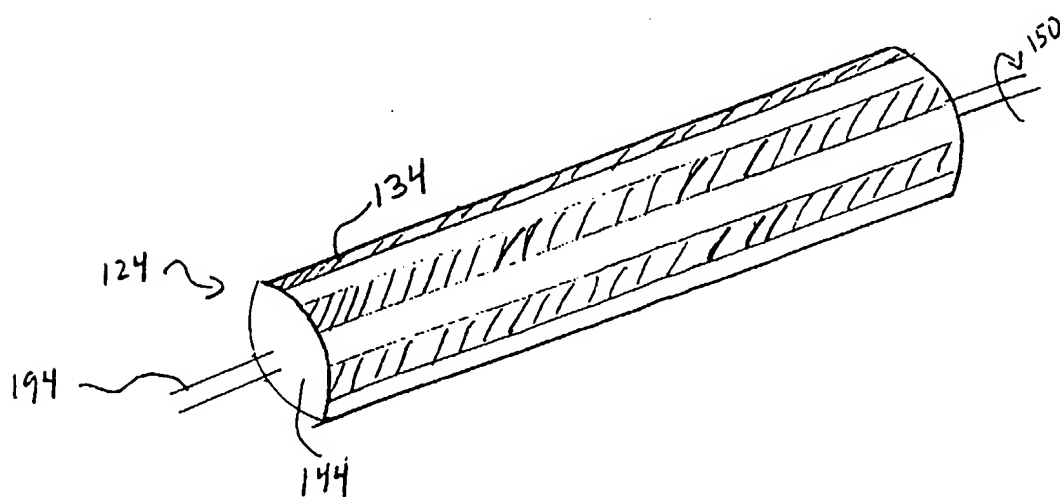


Fig. 4B

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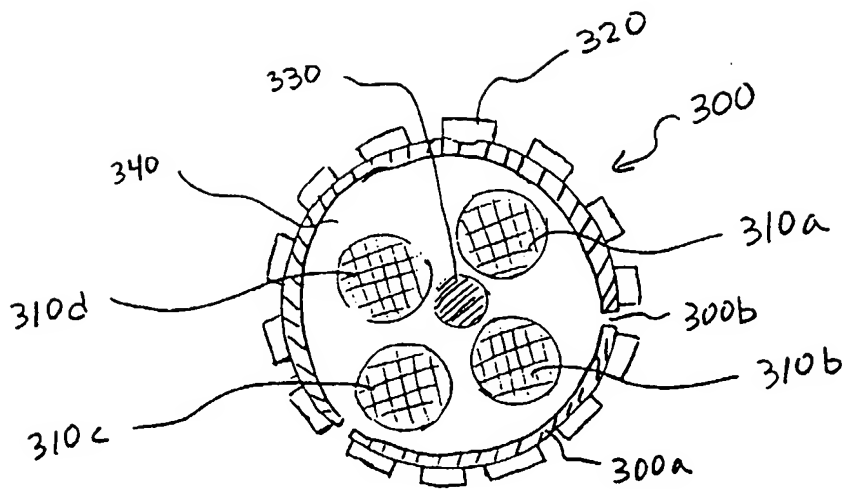


Fig. 5

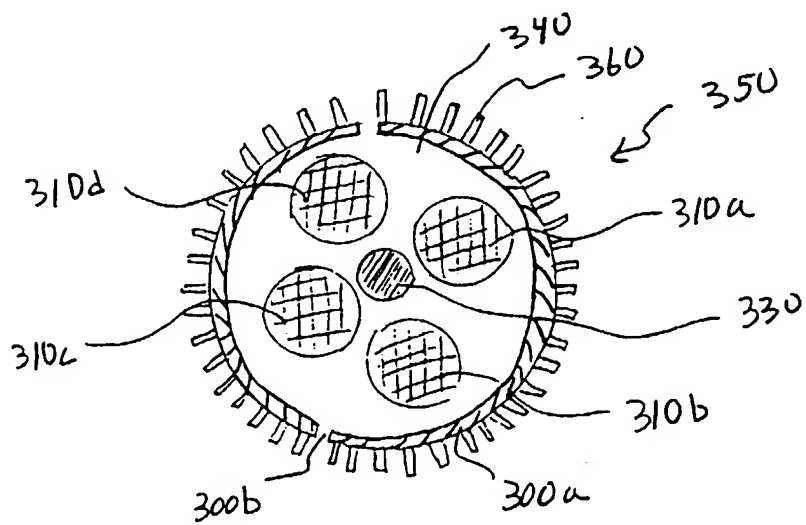


Fig. 6

